Mod 1, 2, 3 → Q1, Q2   Mod 4, 5, 6, 7 → Q3, Q4

$R = V/I$
$V = R \cdot I$
$I = V/R$

~~Components Wireless Tech.~~

Mod 1 Transmission Lines

- lumped components: R, L, C, G
  R [Ω] L [H] G [S] C [F].
  $dV/dz = -(R + j\omega L) I$ $dI/dz = -(G + j\omega C) V$.
- Propagation const: $\gamma = \alpha + j\beta = \sqrt{(R + j\omega L)(G + j\omega C)}$
- $V(z) = V_0^+ e^{-\gamma z} + V_0^- e^{+\gamma z}$.
  $I(z) = I_0^+ e^{-\gamma z} + I_0^- e^{+\gamma z}$.
- characteristic Impedance: $\sqrt{\frac{R + j\omega L}{G + j\omega C}}$ → lossless: $\sqrt{L/C}$
- lossless line: $R = 0 = G$. $G = 1/R$ → conductance.
  ↳ $\gamma = j\beta$ $\beta = \omega\sqrt{LC}$.
  ↳ phase velocity: $v_p = \omega/\beta = 1/\sqrt{LC}$; $\lambda = \frac{2\pi}{\beta} = \frac{2\pi}{\omega\sqrt{LC}}$
- $\Gamma = \frac{Z_L - Z_0}{Z_L + Z_0} = V_0^-/V_0^+$
  $\beta = \frac{2\pi}{\lambda}$
- input impedance: $Z_{in} = Z_0 \frac{Z_L + jZ_0 \tan(\beta l)}{Z_0 + jZ_L \tan(\beta l)}$
- Quarter wave transformer → $l = \frac{\lambda}{4}$.
  → $\beta l = \frac{2\pi}{\lambda} \cdot \frac{\lambda}{4} = \frac{\pi}{2}$ → ~~$\tan(\pi/2) = 0$?~~
  ↳ $\tan(\pi/2) = \infty$.
  $Z_{in} = Z_0 \cdot \frac{Z_0}{Z_L}$
  ↳ $Z_{in} = Z_0^2 / Z_L$
- Perfect match $\sqrt{Z_{in} Z_L} = Z_0$
  ↳ or $Z_2 = \sqrt{Z_1 Z_3}$

- Series: $Z_R = R$; $Z_L = j\omega L$; $Z_C = \frac{1}{j\omega C}$.
- Shunt: $Y_R = 1/R$, $Y_L = 1/j\omega L$; $Y_C = j\omega C$

~~Scatter~~

- Power of reflection: $|\Gamma|^2$ → Power loss due to reflection $1 - |\Gamma|^2$
- $dBm = 10\log_{10}\left(\frac{P_{mW}}{1mW}\right)$ $10^{dB/10} = mW \Rightarrow W$.
  $dB = 10\log_{10}[P_{in}/P_{out}]$

Module 2 - Passive Microwave Networks

A matrix: $\cancel{\begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = A \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}}$ $\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = A \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$.

T matrix: $\begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = T \begin{bmatrix} V_2^+ \\ V_2^- \end{bmatrix}$.

S matrix: $\begin{bmatrix} V_1^- \\ V_2^+ \end{bmatrix} = S \begin{bmatrix} V_1^+ \\ V_2^- \end{bmatrix}$.

$A = D_1 T C_2 \rightarrow$ $T = C_1 T D_2$.

D matrix: decompose: $\frac{1}{2} \begin{bmatrix} 1 & Z \\ 1 & -Z \end{bmatrix} \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix}$.

C matrix: compose: $\begin{bmatrix} 1 & 1 \\ Y & -Y \end{bmatrix} \begin{bmatrix} V_1^+ \\ V_1^- \end{bmatrix} = \begin{bmatrix} V_1 \\ I_1 \end{bmatrix}$.

Module 3 - Antenna Parameters and Theory

- Field Regions of antenna behaviours.
- ~~reactive near field.~~

$R \rightarrow$ distance from antenna.

$D \rightarrow$ dimension of antenna.

$R_1 \rightarrow 0.62 \sqrt{D^3/\lambda}$ $\quad R_2 = 2D^2/\lambda$

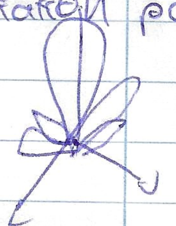
- reactive near field: $R < R_1$
- radiating near field: $R_1 < R < R_2$.
- far field: $R > R_2$. $\quad R \gg D, \lambda \rightarrow$ behave like plane waves

- FSPL $= \left(\frac{4\pi d}{\lambda}\right)^2$

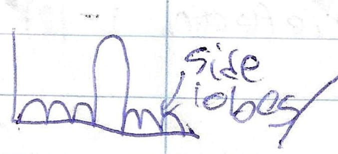
- radius of circle: $r = D/2 \rightarrow \text{Area} = \pi r^2 \rightarrow \pi (D/2)^2 = (\pi D^2/4) \rightarrow$ Ae could be
- gain aperture relation: $A_e/G = \lambda^2/4\pi \rightarrow G = A_e\left(\frac{4\pi}{\lambda^2}\right)$
- Short dipole Ae: $A_{e,max} = 3\lambda^2/8\pi$.
- Friis transmission: $\cancel{P_{rec}} = P_{Rx} = \cancel{G_{Tx}} G_{Rx} P_{tx}\ G_{tx} G_{Rx} \cancel{\log} \left(\frac{\lambda}{4\pi d}\right)^2$

distance between antennas

radiation pattern 3D



radiation pattern 2D



Module 3 - Continue

- $W_{av}(\bar{r}) = 1/2 \, Re(\bar{E}(\bar{r}) \times \bar{H}^*(\bar{r}))$: time avg power density.
- radiation intensity (distance independent): $U(\theta,\varphi) = R^2 W_{av}(\bar{r})$

- directivity: $D_g = \frac{U(\theta,\varphi)}{U_0}$ $\quad U_0 = P_{rad}/4\pi$
- gain: $G_g = 4\pi U(\theta,\varphi)/P_{in}$ $\frac{4\pi}{P_{in}} U(\theta,\varphi)$

→ gain to directivity: $G_g = e_t D_g$

e_t → radiation efficiency (Power based)

$e_t = P_{rad}/P_{in} = \frac{R_{rad}}{R_{rad} + R_{loss}}$

$e_t = e_r e_{cd}$ → $e_r = 1 - |\Gamma|^2$ → reflection loss

↳ e_{cd} → conduction / dielectric loss

Polarization

→ orientation / trajectory

$E_\theta = \bar{E_\theta} \cos(\omega t - kR + \varphi_\theta)$.

$E_\varphi = \bar{E_\varphi} \cos(\omega t - kR + \varphi_\varphi)$.

- Axial ratio: $AR = \frac{\max(E_\theta \bar{a}_\theta + E_\varphi \bar{a}_\varphi)}{\min(E_\theta \bar{a}_\theta + E_\varphi \bar{a}_\varphi)}$ → linear: ∞ → circular: 1 → eliptical $1 < AR < \infty$

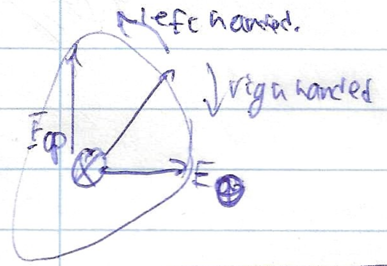
- linear: $\Delta\varphi = \varphi_\theta - \varphi_\varphi = n\pi \quad \in N_0$.

circular: $\bar{E_\theta} = \bar{E_\varphi}$; $\Delta\varphi = \varphi_\theta - \varphi_\varphi = \pm(1/2 + 2n)\pi$, $n \in N_0$.

eliptical: $\bar{E_\theta} \neq \bar{E_\varphi}$; $\Delta\varphi = \varphi_\theta - \varphi_\varphi = \pm(1/2 + 2n)\pi$ $n \in N_0$

$\Delta\varphi = \varphi_\theta - \varphi_\varphi \neq \pm n/2\,\pi, n \in N_0$ → tilted ellipse

↑ rotation direction.



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abs bandwidth: $BW = f_{max} - f_{min}$.

% narrowband bandwidth: $p = BW/f_c$.

efficiency eg $eff = 20\%$

$G_g = D_g \cdot e_t$

$G_g = 10\log_{10}(D_g) + 10\log_{10}(0.2)$

Effectrice Aperearee

received power: $P_T = W_{inc} A_e$.

effective apereure general form: $A_e = \frac{P_T}{W_{inc}} = \frac{V_T^2}{2W_{inc}\left((R_T + R_{rad} + R_{loss})^2 + (X_T + X_A)^2\right)}$

Matched case:

max aperture: $A_e = \frac{V_T^2}{8 W_{inc}(R_{rad} + R_{loss})}$

short dipole: $A_e = 3\lambda^2/8\pi$ $\quad$ eg: area: $\pi r^2 = A_e \to r = D/2$.

$\downarrow G_{max} = 1.5$

(plane wave in free space)

- power density: $W_{inc} = E^2/2\eta$ $\quad \eta = 120\pi$ free space.

radiation efficiency

$\eta = \frac{P_{rad}}{P_{in}} = \frac{R_{rad}}{R_{rad} + R_{loss}}$

- Aperture-gain link = $A_e/G = \lambda^2/4\pi$

Propagation Channel

FSPL: $\left(\frac{4\pi d}{\lambda}\right)^2$

~~$P_{rec} = P$~~

$P_{Rx} = P_{Tx}\, G_{Tx}\, G_{Rx} \left(\frac{\lambda}{4\pi d}\right)^2$

- Isotropic Power density at distance: $W_{inc, iso} = \frac{P_{rad}}{4\pi R^2}$

Polarization Determine

linear: $1e^{j\omega t}\bar{x} + 0e^{j\omega t}\bar{y}$

$0e^{j\omega t}\bar{x} + 2e^{j\omega t}\bar{y}$

$1e^{j\omega t}\bar{x} + 1e^{j\omega t}\bar{y}$ → $2\pi, 3\pi$ etc → $\theta - \phi = n\pi$ number

$5e^{j\omega t}\bar{x} + 2e^{j(\omega t+\pi)}\bar{y}$

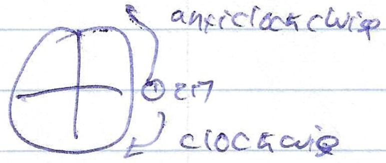
---

circular: (−) - RA clockwise (+) - KH anticlockwise $n\pi/2 = \theta - \phi$

$E_\theta = E_\phi$.

$1e^{j\omega t}\bar{x} + 1e^{j(\omega t+\pi/2)}\bar{y}$

$2e^{j\omega t}\bar{x} + 2e^{j(\omega t-5\pi/2)}t.$



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elliptical: (−) - clockwise (+) - anticlockwise

$E_\theta \neq E_\phi$; $n\pi/2 = \theta - \phi$ or if $\frac{n}{2}\pi$ → tilted. ellipse

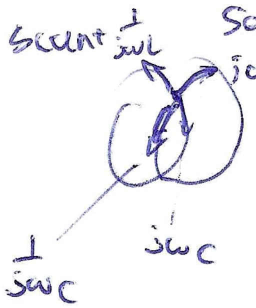
$1e^{j\omega t}\bar{x} + 2e^{j(\omega t+\pi/2)}\bar{y}$ normal.

$1e^{j\omega t}\bar{x} + 2e^{j(\omega t+\pi/4)}\bar{y}$ tilted.

$8.84 \cdot 10^{-13}$

4 GHz

1.



$\cancel{\frac{1}{j\omega L}}$ = moved to $-0.9j = z$

$\cdot 50 \rightarrow -45j = \cancel{z}$

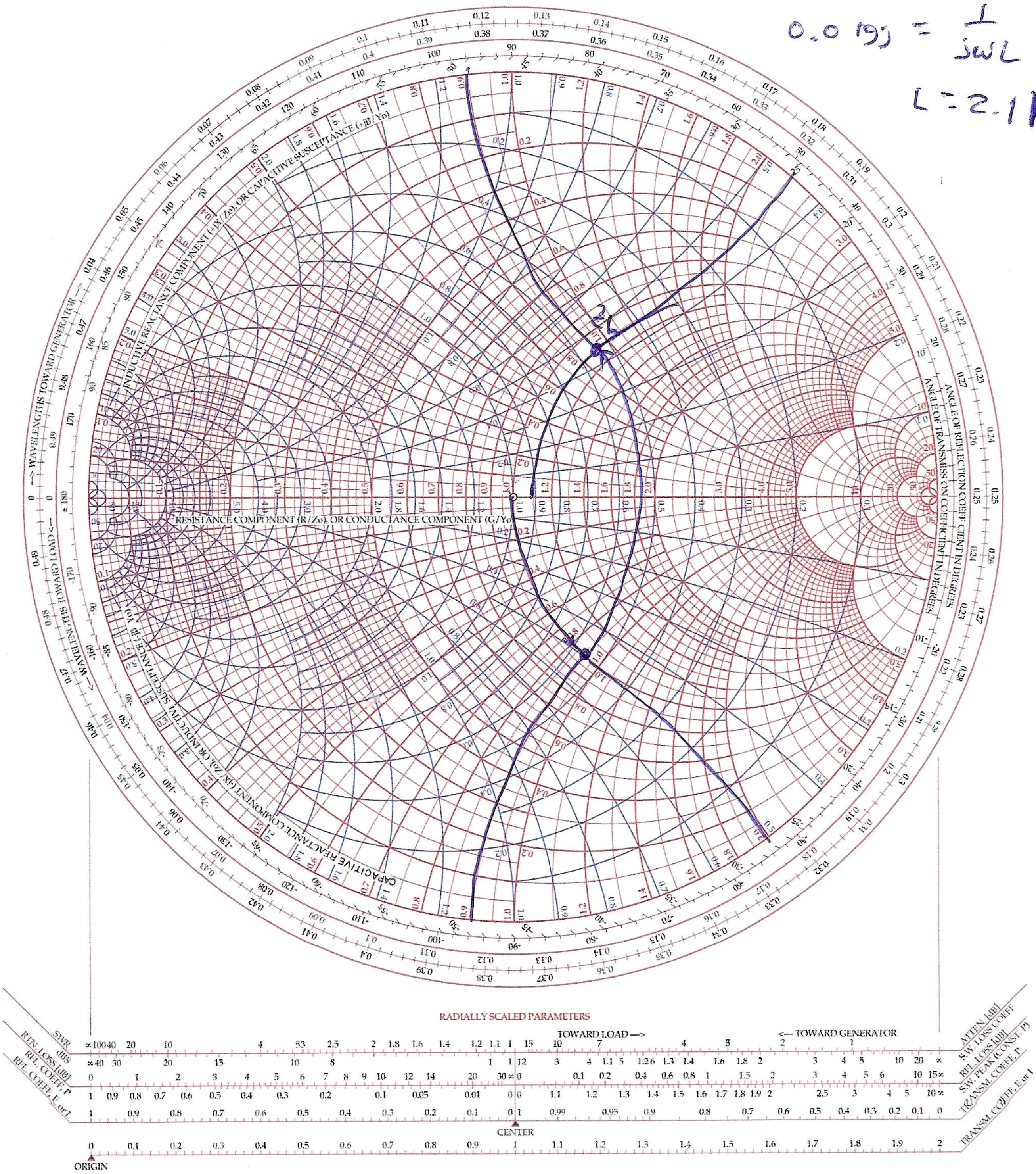
$\cancel{j\omega L}$ $\frac{1}{j\omega C} = -45j \rightarrow C = 0.88\,pF.$

2. moved: $(0.5 - -0.45j) = 0.95j$

$\cancel{0.28}\ 0.95j \cdot \frac{1}{50} = 0.019j$

$0.019j = \frac{1}{j\omega L}$

$L = 2.1\,nH$



• RF systems: signal conditioning to minimize:
- noise
- nonlinearity
- energy loss

(mic) input → Filter etc.. → loudspeaker

• high frequency RF needs account for parasitics

• RF blocks: Transceiver: LNA, PA, mixers, Filters

List of Equations (only some of these equations are required to solve question 3 and 4)

$\Gamma_L = \frac{Z_L - Z_S}{Z_L + Z_S}$

Power definitions

Power delivered to the load	$P_L = \frac{\lvert V_2^-\rvert^2}{2Z_0}\left(1-\lvert\Gamma_L\rvert^2\right)$
Input power to the network	$P_{in} = \frac{\lvert V_1^+\rvert^2}{2Z_0}\left(1-\lvert\Gamma_{in}\rvert^2\right)$ ~~Power gain~~ $G = \frac{P_L}{P_{in}}$ → power gain
Input and output reflection coefficients of a transistor with a source and load: general case	$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}$ $\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}$
Input and output reflection coefficients of a transistor with a source and load: unilateral case max $G_{TU,max}$ achieved	$\Gamma_{in} = \frac{V_1^-}{V_1^+} = S_{11}$ $\Gamma_{out} = \frac{V_2^-}{V_2^+} = S_{22}$ $S_{12} = 0$ meaning only dependent on original signal ~~nothing~~ to no interaction with port 2->1 travelling waves
Gain of the input matching network	$G_S = \frac{1-\lvert\Gamma_S\rvert^2}{\lvert 1-\Gamma_{in}\Gamma_S\rvert^2}$
Gain of the output matching network	$G_L = \frac{1-\lvert\Gamma_L\rvert^2}{\lvert 1-S_{22}\Gamma_L\rvert^2}$
Gain of the transistor (unilateral case)	$G_0 = \lvert S_{21}\rvert^2$
Transducer gain of the basic amplifier circuit (input matching, unilateral transistor, output matching)	$G_T = G_S G_0 G_L$ ← also unilateral. $G_{T,dB} = G_{S,dB} + G_{0,dB} + G_{L,dB}$
Maximum gain of the input and output matching networks	$G_{S_{max}} = \frac{1}{1-\lvert S_{11}\rvert^2}$, $G_{L_{max}} = \frac{1}{1-\lvert S_{22}\rvert^2}$. $S_{12} = 0$.
Maximum transducer power gain, unilateral case	$G_{TU_{max}} = \frac{1}{1-\lvert S_{11}\rvert^2}\lvert S_{21}\rvert^2\frac{1}{1-\lvert S_{22}\rvert^2}$ $G_{TU_{max}} = G_{S_{max}} G_0 G_{L_{max}}$
Normalized gain factors g_s and g_L	$g_S = \frac{G_S}{G_{S_{max}}} = \frac{1-\lvert\Gamma_S\rvert^2}{\lvert 1-S_{11}\Gamma_S\rvert^2}(1-\lvert S_{11}\rvert^2)$, $g_L = \frac{G_L}{G_{L_{max}}} = \frac{1-\lvert\Gamma_L\rvert^2}{\lvert 1-S_{22}\Gamma_L\rvert^2}(1-\lvert S_{22}\rvert^2)$.
Center and radius of the constant gain circle for the input matching network	$C_S = \frac{g_S S_{11}^*}{1-(1-g_S)\lvert S_{11}\rvert^2}$, $R_S = \frac{\sqrt{1-g_S}\,(1-\lvert S_{11}\rvert^2)}{1-(1-g_S)\lvert S_{11}\rvert^2}$
Center and radius of the constant gain circle for the output matching network	$C_L = \frac{g_L S_{22}^*}{1-(1-g_L)\lvert S_{22}\rvert^2}$, $R_L = \frac{\sqrt{1-g_L}\,(1-\lvert S_{22}\rvert^2)}{1-(1-g_L)\lvert S_{22}\rvert^2}$

2-port network

gains

constant gain circles

• Depict ~~specific~~ impedance matching conditions for specific power gain value.

• points on circle load, source impedance to produce specified gain.

There is 2 types of smith chart circles:

1) stability circles 2) Constant Gain Circles.

Mod5 Noise and LNA Design

- Thermal Noise Power: $P_n = k_B T B$ → BW. (temp kelvin; Boltzman const)
- white noise: $P_n = \frac{V_n^2}{4R_N} = k_B T B$
- Noise Temp: $T_e = N_o / k_B B$

Noise sources

- thermal, shot, flicker (1/f)
- burst (random telegraph)
- avalanche (carrier multip)

LNA focus

- high gain
- input/output matching
- low noise figure
- stability across operating bands/

Design for specific noise figure

- Γ_{opt}, r_n, F_{min} known transistor.
- amplifier specification requires noise figure: F and gain G.

1. calc N (noise figure)
2. calc C_F, R_F
3. draw circles for the required F and input section constant gain circle for several G_S.
4. choose Γ_S that on desired noise circle and gain circle.
5. remaining gain come from transistor/output matching stage.

Mod6 Basics of Power Amplifiers and Mixers - Theory and Formulas

- Small signal params:
  1. gain
  2. noise fig [NF].
  3. Input Third-Order Intercept Point IIP3.
  4. Input 2nd-order Intercept Point IIP2.
- large signal params
  1. 1dB. compression point (P1dB).

available noise power

$$P_n = \frac{V_n^2}{4R_N} = k_B T B.$$

- non linearity device output:

$$v_{out}(t) = a_1 v_{in}(t) + a_2 v_{in}^2(t) + a_3 v_{in}^3(t) + \dots$$

- cascade IIP3:

$$\frac{1}{IIP3^2_{total}} = \frac{1}{IIP3_1^2} + \frac{1}{G_{a,1}^2 IIP3_2^2} + \dots$$

Mixer

Rx-case — down conversion

mixer time-domain output:

$$x_{IF}(t) = A_{RF} A_{LO} \cos(\omega_{RF} + \omega_{LO}) + \cos(\omega_{RF} - \omega_{LO}).$$

Intermediate freq:

$$\omega_{IF} = \omega_{RF} - \omega_{LO}.$$

freq domain: $X_{out}(\omega) = X_{in}(\omega) * X_{LO}(\omega)$

Tx case - upconversion

$$\omega_{RF} = \omega_{IF} + \omega_{LO}$$

Power Amplifier

$$P_{load} = \frac{V_{load}^2}{R_L} \qquad \eta_{max} = \frac{\pi}{4} \approx 78.5\%$$

$$R_L = \frac{2V_{DD} - V_{min}}{I_{max}}$$

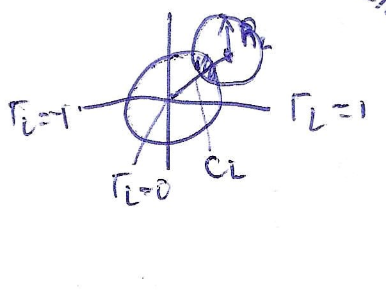
PA Performance params

- P1dB: output 1dB compression point.
- P_{max}: max output power achievable.
- efficiency: ratio of RF output power to DC input power

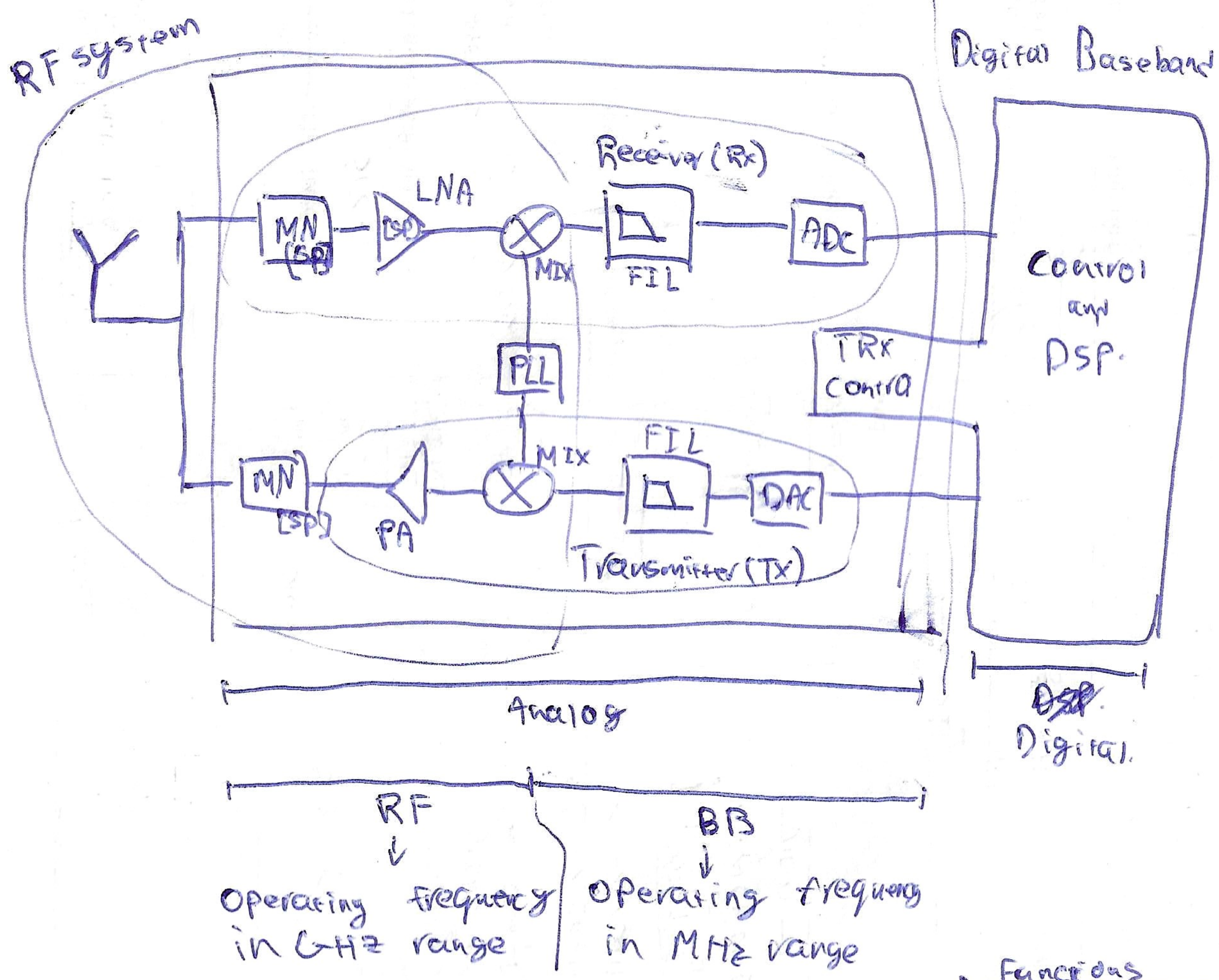
• unilateral amplifier : no feedback to its input side → $S_{12} = 0$.

stability	**Condition for "unconditionally stable" device, general case**	for all $\lvert\Gamma_L\rvert<1$ and $\lvert\Gamma_S\rvert<1$ $$\Rightarrow \begin{cases} \lvert\Gamma_{in}\rvert = \left\lvert S_{11} + \frac{S_{12}S_{21}\Gamma_L}{1-S_{22}\Gamma_L}\right\rvert < 1 \\ \lvert\Gamma_{out}\rvert = \left\lvert S_{22} + \frac{S_{12}S_{21}\Gamma_S}{1-S_{11}\Gamma_S}\right\rvert < 1 \end{cases}$$
	Conditions for "unconditionally stable" device, unilateral case S_{12} -	$\lvert\Gamma_{in}\rvert = \lvert S_{11}\rvert < 1$ stable $\lvert\Gamma_{out}\rvert = \lvert S_{22}\rvert < 1$ $S_{12} = 0$.
Stability circles.	**Center and radius of the stability circles, load side** draw theses circles to find unstable regions of amplifier.	$C_L = \frac{(S_{22}-\Delta S_{11}^*)^*}{\lvert S_{22}\rvert^2 - \lvert\Delta\rvert^2}$ (center), $R_L = \left\lvert\frac{S_{12}S_{21}}{\lvert S_{22}\rvert^2-\lvert\Delta\rvert^2}\right\rvert$ (radius). $\Delta = S_{11}S_{22} - S_{12}S_{21}$ • identify stable regions of operation in amplifier. • C → center R → radii.
	Center and radius of the stability circles, source side	$C_S = \frac{(S_{11}-\Delta S_{22}^*)^*}{\lvert S_{11}\rvert^2 - \lvert\Delta\rvert^2}$ (center). $R_S = \left\lvert\frac{S_{12}S_{21}}{\lvert S_{11}\rvert^2-\lvert\Delta\rvert^2}\right\rvert$ (radius) $\Delta = S_{11}S_{22} - S_{12}S_{21}$! Γ_S, Γ_L fall inside circle reflections in stability region → means unstable
Stability analysis	**Test for unconditional stability, general case**	$\lvert\Delta\rvert = \lvert S_{11}S_{22} - S_{12}S_{21}\rvert < 1$ **and** $K = \frac{1-\lvert S_{11}\rvert^2 - \lvert S_{22}\rvert^2 + \Delta^2}{2\lvert S_{12}S_{21}\rvert} > 1$
	Test for unconditional stability, unilateral case	$\lvert S_{11}\rvert < 1$ $\lvert S_{22}\rvert < 1$ $S_{12} = 0$
noise figure	**Noise figure of a 2-port amplifier**	$F = F_{\min} + \frac{r_N}{g_S}\lvert \underline{y}_S - \underline{y}_{opt}\rvert^2$ admittance form $F = F_{\min} + 4r_N\frac{\lvert\Gamma_S-\Gamma_{opt}\rvert^2}{(1-\lvert\Gamma_S\rvert^2)\cdot\lvert 1+\Gamma_{opt}\rvert^2}$ reflection coeff form.
Const noise circles	**Constant noise circles** • help select Γ_S for desired F in LNA input matching noise figure parameter N:	$C_F = \frac{\Gamma_{opt}}{1+N}$ center $R_F = \frac{1}{1+N}\sqrt{N^2+N(1-\lvert\Gamma_{opt}\rvert^2)}$ radius.] 2. $F_{min} = 10^{\frac{NF_{min}}{10}}$ $\Delta F_n' = N = (F - F_{\min})\frac{\lvert 1+\Gamma_{opt}\rvert^2}{4r_n} = \frac{\lvert\Gamma_S-\Gamma_{opt}\rvert^2}{1-\lvert\Gamma_S\rvert^2}$ 1

• if $\lvert S_{11}\rvert < 1$ and $\lvert\lvert C_L\rvert - R_L\rvert > 1$ → 2 port unconditionally stable//



Analog Transceiver (TRx) - Radio



TRX functions
- Data conversion
- Filtering / selectivity
- Frequency conversion
- Amplification
- Frequency synthesis

Legend

RF - radio Frequency
BB - baseband.
MN - Matching network.
LNA - low noise amplifier
MIX - mixer
FIL - filter
PA - Power amplifier.
ADC - Analog to Digital Converter
DAC - Digital to Analog Converter
DSP - Digital Signal Processing
PLL - phased Locked Loop.

Functions	Building block	Symbol
1. digitization	ADC	IN — ADC — Out
2. Amplification	Amplifier	IN — ▷ — Out
3. Filtering	Filter	In — [filter] — Out
4. frequency conversion	Mixer	IN — ⊗ — Out. LO

• SFDR, LDR → usable range of system without significant distortion.

• linear dynamic range: $LDR = P_{1dB} - P_{noise}$

• Spurious-Free Dynamic Range: $SFDR = 2/3(IIP3 - P_{noise})$

Output noise, input noise, equivalent noise temperature, noise factor and noise figure noise and LNA design	$N_o = Gk_B(T_0 + T_e)B$ $N_i = k_B T_0 B$ $F = \frac{\frac{S_i}{N_i}}{\frac{S_o}{N_o}} = \frac{S_i}{S_o}\frac{N_o}{N_i} = \frac{1}{G}\frac{Gk_B(T_0+T_e)B}{k_B T_0 B} = 1 + \frac{T_e}{T_0}$ SNR in / SNR out $NF = 10\log_{10} F$
Three-stage amplifier: **Output noise ($P_{n,total}$), noise factor (F_{total}) noise figure (NF_{total})** $T_{e,total} = T_{e,1} + \frac{T_{e,2}}{G_1} + \frac{T_{e,3}}{G_1 G_2} + \ldots$ →	$P_{n,total} = G_{A3}G_{A2}G_{A1}P_{n,in} + G_{A3}G_{A2}P_{n1} + G_{A3}P_{n2} + P_{n3}$ $F_{total} = \frac{P_{n,total}}{G_{A3}G_{A2}G_{A1}P_{n,in}}$ $F_{total} = 1 + \frac{P_{n1}}{G_{A1}P_{n,in}} + \frac{P_{n2}}{G_{A1}G_{A2}P_{n,in}} + \frac{P_{n3}}{G_{A3}G_{A2}G_{A1}P_{n,in}}$ $F_{total} = F_1 + \frac{F_2-1}{G_{A1}} + \frac{F_3-1}{G_{A1}G_{A2}}$ → in watts. $10\log_{10}$ (dB) $NF_{total} = 10\log_{10} F_{total}$ Noise factor of single stage $F_j = 1 + \frac{P_{nj}}{G_{Aj}P_{n,in}}, j = 1,2,3$ Noise figure of single stage $NF_j = 10\log_{10} F_j, j = 1,2,3$
Receiver sensitivity ↑LNA influenced by receiver sensitivity. $P_{source} = -174 dBm/Hz$ for $T_0 = 290K$	$10\log_{10}(\ldots)$ $P_{sens}\,[dBm] = k_B T_0 B[dBm] + NF_{total}[dB] + SNR[dB]$ $P_{sens}\,[dBm] = -174 + NF_{total} + 10\log_{10} B + SNR$ k_B – Boltzman constant, $k_B = 1.38 \cdot 10^{-23} \frac{Watt \cdot s}{K}$
Conversion Watt to dBm	$P_{sens}\,[dBm] = 10\log_{10}\frac{P_{sens}\,[Watt]}{1mWatt}$ $P_{sens}\,[dBm] = 10\log_{10}\frac{P_{sens}\,[Watt]}{10^{-3}Watt}$
Gain conversion from linear to dB	$G\,[dB] = 10\log_{10} G$
Friis radio link formula • Shanon Capacity: $C = B \cdot \log_2(1+SNR)$. • received power: $P_{Rx} = P_{Tx} + G_{Tx} + G_{Rx} - L_{path} - L_{cables}$	$P_{RX} = P_{TX}G_{TX}G_{RX}(\frac{\lambda}{4\pi R})^2$ P_{RX} – power at RX input P_{TX} – power at TX output G_{RX} – RX antenna gain G_{TX} – TX antenna gain λ – wave length $\lambda = \frac{c}{f}$ c – speed of light, $c = 3 \cdot 10^8 \frac{m}{s}$ f – frequency

$FSPL = \left(\frac{4\pi R}{\lambda}\right)^2$

• Bit Error Rate (BER)
↳ depends on:
↳ snr
↳ modulation scheme.

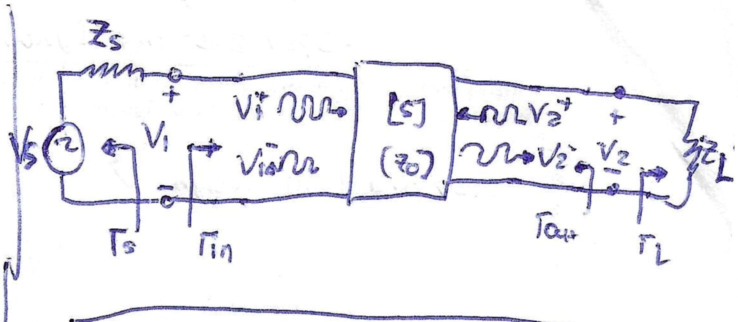
• energy per bit: $E_b = \frac{S}{R_b}$

• noise power: $N = N_0 \cdot B$.

• ratio: $E_b/N_0 = \frac{S}{N} \cdot \frac{B}{R_b}$

Amplifier Gain Equations that are missing.

module 4



given: $P_L = \frac{|V_2^-|^2}{2Z_0}(1-|\Gamma_L|^2)$

$P_{in} = \frac{|V_1^+|}{2Z_0}(1-|\Gamma_{in}|^2)$

not:

P_{avs} → Power available from source: $Z_S^* = Z_{in}$

P_{in} → when source impedance is conjugately matched to input impedance

$P_{avs} = \frac{|V_S|^2}{2Z_0}(1-|\Gamma_S|^2)$

P_{avn} → Power available from network: $Z_L^* = Z_{out}$

P_L → when load impedance is conjugately matched to output impedance

$P_{avn} = \frac{|V_2^-|^2}{2Z_0}(1-|\Gamma_{out}|^2)$

Power Gain: $G = \frac{P_L}{P_{in}} = \frac{|S_{21}|^2(1-|\Gamma_L|^2)}{(1-|\Gamma_{in}|^2)|1-S_{22}\Gamma_L|^2}$

Available Power Gain: $G_A = \frac{P_{AVN}}{P_{AVS}} = \frac{|S_{21}|^2(1-|\Gamma_S|^2)}{|1-S_{11}\Gamma_S|^2(1-|\Gamma_{out}|^2)}$

Traducer Power Gain: $G_T = \frac{P_L}{P_{AVS}} = \frac{P_L}{P_{avs}} = \frac{|S_{21}|^2(1-|\Gamma_S|^2)(1-|\Gamma_L|^2)}{|1-\Gamma_S\Gamma_{in}|^2|1-S_{22}\Gamma_L|^2}$

unilateral ~~P~~ Traducer power gain → G_{TU} → given.